

**Economic Growth and Automobile Dependence:
Is There A Kuznets Curve for Motorization?**

by

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Submitted to the Department of Urban Studies and Planning
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ABSTRACT

The motivation of this research is to fill a gap in the existing research in terms of understanding the long-term dynamics of motorization process. The goal is to investigate--both theoretically and empirically--the long-term relationship between economic development and motorization, and specifically to find if there is an inverse-U relationship (i.e., if there is a Kuznets curve for motorization). Such an understanding provides analysts with a way to improve forecasts of the level of motorization in the long-run as well as with a reliable estimate of associated externality costs--both at global and national levels. It is thus a critical ingredient to the development of sustainable motorization policies. The identification of the turning point per capita income level, if any, is also helpful in crafting motorization policies that are consistent and appropriate for different stages of economic development.

The research makes several distinctive contributions to the existing literature. First, it is the only study to explore--both theoretically and empirically--the possible existence of a Kuznets curve for motorization. Second, the theoretical analysis clearly demonstrates the plausibility of the existence of an inverse U-relationship between economic development and motorization. Further, the empirical analysis not only provides strong support for the existence of a Kuznets curve for motorization, but also shows that the Kuznets curve does indeed provide a statistically better description of the long-term relationship between economic development and motorization (in terms of per capita ownership) than either the sigmoidal or the log-linear form commonly used in the existing literature. Finally, the cross-country, time-series data base developed for the empirical analysis is much larger than any used in the existing studies on economic development and motorization.

It should be emphasized that there is no reason to believe that the detected inverse-U relationship between economic development and motorization is automatic or inevitable. The pattern detected is only a reflection of existing policies under the prevailing socio-economic, technological and political conditions. As with the environmental Kuznets curve, the strongest link between economic development and motorization is, in fact, through an *induced policy response*. Our relatively high estimate of the turning point per capita income at about \$21,900 (1993 US\$) stems from the fact that, even though most of developed countries already have the institutional capability, it is only recently that public attitude has changed enough to allow hitherto politically unacceptable, but effective, policy interventions to control motorization. As the externality costs of motorization become more apparent, developing countries have the opportunity to avoid following the current motorization-development path through preemptive policy interventions. The turning point is thus likely to decline over time.

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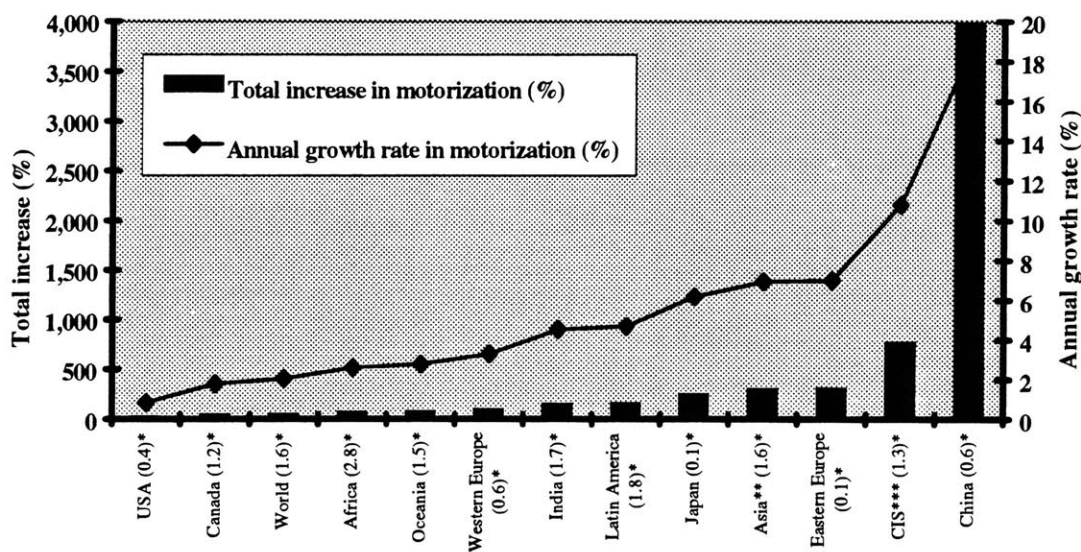
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CHAPTER 1: The Research Issue and Objectives

1.1 The Context: Mass Motorization and Rising External Cost

Since the first car rolled out of its primitive production line in 1896, it has gone on to establish itself as the world's largest consumer product with current annual sales approaching a trillion dollars. Passage of time has only deepened consumers' love affair with car. In 1950, 50 million cars shared the earth with 2.6 billion people. By 1996, the totals had grown to 500 million cars (and that excludes another 277 million in trucks and motorbikes) and 5.5 billion people. In other words, as the human population doubled, the stock of cars increased tenfold. Country-specific rates vary substantially but, with the exception of Africa, the pace is higher in developing and transition economies than in North America and Western Europe (see Figure 1.1). Although economic factors (e.g., the rising income and

Figure 1.1. Trends in motorization (passenger cars per 1,000 population) in selected countries and regions, 1970-1990



Note: "*" indicates average annual population growth rate between 1970-1990 for respective country or region.

"**" indicates Asia excluding China, Japan and India.

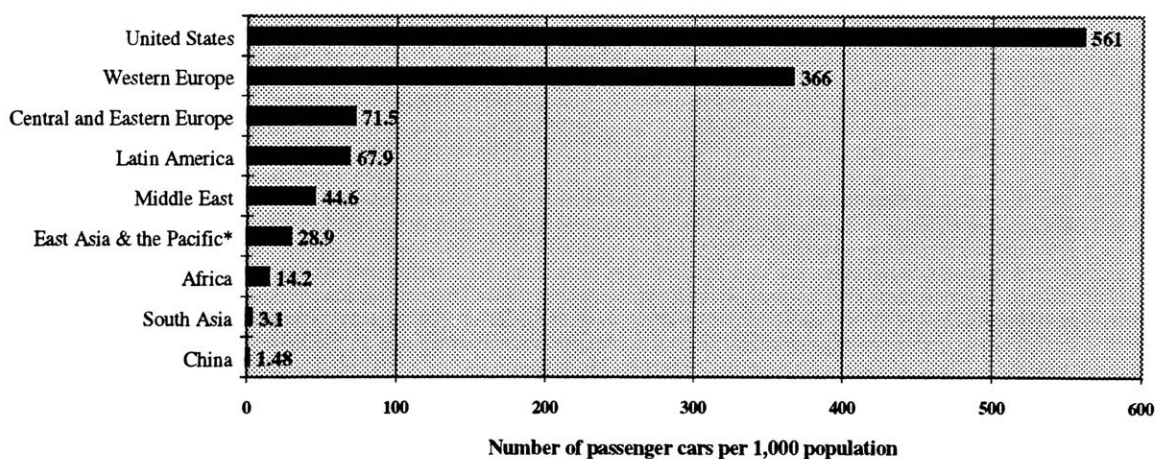
"***" CIS stands for the Commonwealth of Independent States (former Soviet Union countries)

Sources: AAMA [1992]; Renner [1988]; United Nations [1995].

the declining price of cars) are arguably the primary driving forces behind such rapid growth in car ownership, social and cultural factors (e.g., the declining household size and the increasing participation of women in workforce) are responsible for further accelerating the pace. Assembly lines today roll out 50 million cars a year--that is adding in a year more than what consumers accumulated in the first fifty years of its initial roll out! Based on current trends, the world's car population is expected to double itself to 1 billion by 2025 or 2030 [Carson 1996].

Stimulated by increased economic liberalization and a growing urban population with rising per capita income, developing and transition countries of Eastern Europe and Asia offer the fastest growing market to domestic and OECD car manufacturers. Judging by the levels of passenger cars per capita reached in developed countries, the market potential looks enormously attractive (see Figure 1.2). Not surprisingly, the world's big car companies are eagerly setting up joint-venture production facilities in South East Asia, Eastern Europe and Latin America [Carson 1996]. Recent forecasts show that motor-vehicle (which includes both passenger and commercial vehicles) sales in Asia will surpass that in North America and Europe by 2005, when they are projected to hit nearly 19 million a year [Cox 1996].

Figure 1.2. Passenger cars per 1,000 population in selected countries and regions (1993)



Note: "*" indicates East Asia and the Pacific excluding China and Japan.

Source: WRI [1996].

By conservative estimates, Asians will buy 7% to 8% more vehicles each year well into the next decade, compared to 2% to 3% more a year for North Americans and Europeans. Many Asian countries like China, India, Indonesia, Malaysia and Thailand will see double-digit growth in their annual automobile sales. The emerging consensus is that the world is experiencing mass motorization¹ [Altshuler and Roos 1984; Lowe 1990; OECD 1995; World Bank 1996; WRI 1996].

As the reality of mass motorization begins to sink in, the focus is shifting to its implications. The benefits are obvious--tell-tale signs of a prospering world in pursuit of greater freedom through increased mobility. Some developing and transition countries would like to emulate the wealth and inter-industry linkages created by the car industry in developed countries. However, the externality costs of motorization are also becoming more and more apparent [MacKenzie et al. 1992; Roberts 1995]. Recent estimates put the total externality cost of motorization in developed countries at about 2% of gross domestic product² (GDP), with congestion and accident costs contributing nearly 80% of it [BTCE/EPA 1994; OECD 1990a]. Estimates for developing countries are few but are generally considered to be higher. For example, road accidents alone costs Kenya about 1.3% of its GDP [World Bank 1996]. We discuss the externality costs of motorization in greater detail in Chapter 2.

Not surprisingly, the degree of dependence on motorized road transport--with its problems of traffic accidents, congestion, pollution and urban sprawl--is fast emerging as a critical public policy issue [*Economist* 1996a; Gerondeau 1996; Hart and Spivak 1993; Newman and Kenworthy 1996; Roberts 1995]. Even as the debate on the accuracy of the estimates of the externality costs of motorization continues, there is an emerging consensus that the current pace of motorization is too high to sustain without its costs soon outweighing its benefits [Lowe 1990; MacKenzie and Walsh 1990;

¹ Motorization, usually defined to describe the dependence of a country or a region on motorized road transport, can be measured in many ways. For the purpose of this research, we adopt the most commonly used measure, viz., per capita motor vehicle ownership in a country [Stares and Liu 1995].

² For rest of the paper, we will use the abbreviations GDP and GNP to denote gross domestic product and gross national product, respectively.

OECD 1988, 1994, 1995; World Bank 1996; WRI 1996]. Hence, the impetus is to come up with policies that will put motorization on a “sustainable” time path [Banister and Button 1993; Dugonjic et al. 1993; Nijkamp 1994; Throsby 1993].

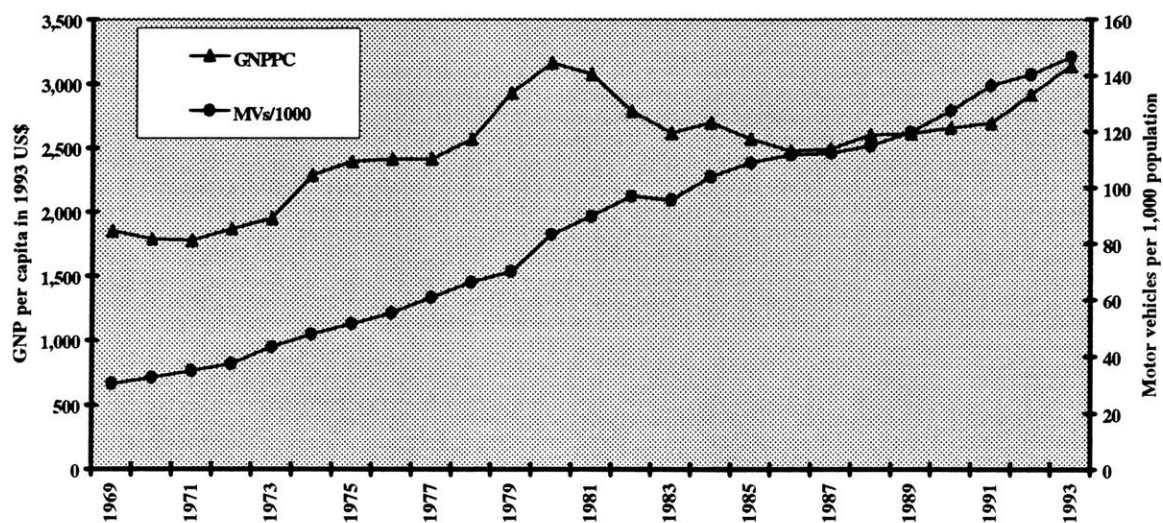
1.2 Research Motivation and Relevance

With likely investment of hundreds of billions of dollars in surface transport over the next two or three decades in developing and transition economies, the need for sustainable motorization policies is more relevant than ever [World Bank 1994a, 1996]. An essential ingredient to the development of such sustainable motorization policies is a reliable forecast of long-term trends in motorization and its associated externality costs--both at global and national levels. For example, automobile emissions account for 20% of world carbon dioxide output--a primary greenhouse gas responsible for global warming. So a reliable forecast of long-term trends in motorization is critical to the studies of future global warming trends and to the development of sustainable motorization policies [Carson 1996]. The ability to come up with such a reliable forecast, in turn, depends on how good is our understanding of the long-term dynamics between economic development and motorization.

Naturally, the long-term relationship between economic development and motorization has been an active area of research in transportation economics [Hau 1997; Stares and Liu 1995]. The popular notion has been that “there is an inevitable link between rising living standards and rising demands for private space and car use” [Newman et al. 1995]. Such a notion draws directly from casual empiricism that is replete with evidence that economic growth fuels motorization (see Figures 1.3 and 1.4). Accordingly, existing research posits either a continuous positive relationship between motorization and income (log-linear models) or a saturation level of motorization at high income (sigmoidal or quasi-logistic models) [Gakenheimer and Steffes 1995]. Although formal empirical studies³ have usually

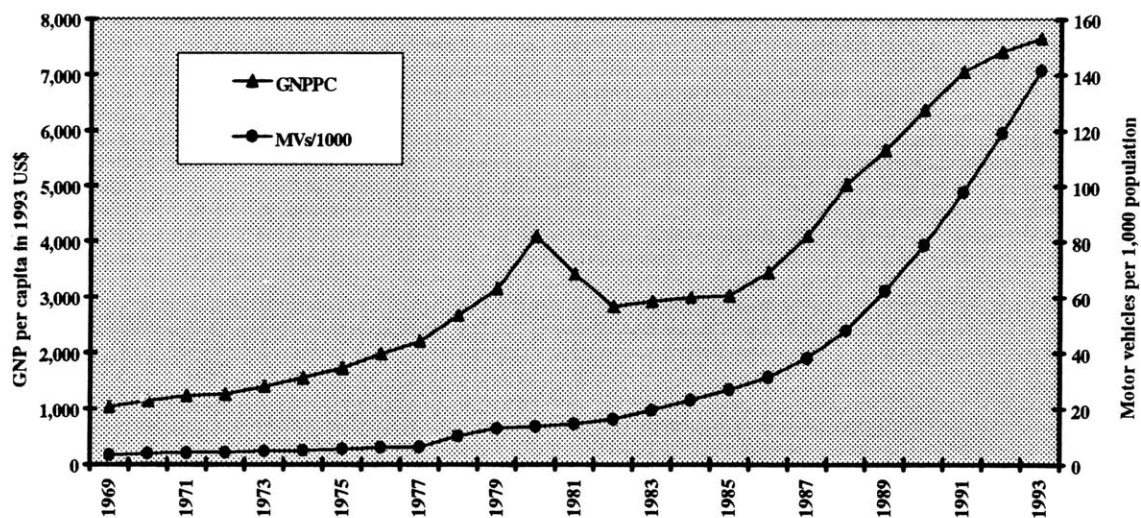
³ See, for example, Button et al. [1993], Kain [1983], Kain and Liu [1994], Mogridge [1989], Silberston [1970] and Wheaton [1980].

Figure 1.3. Economic development and motorization trends in Malaysia, 1969-1993



Sources: United Nations [1995]; World Bank [1995].

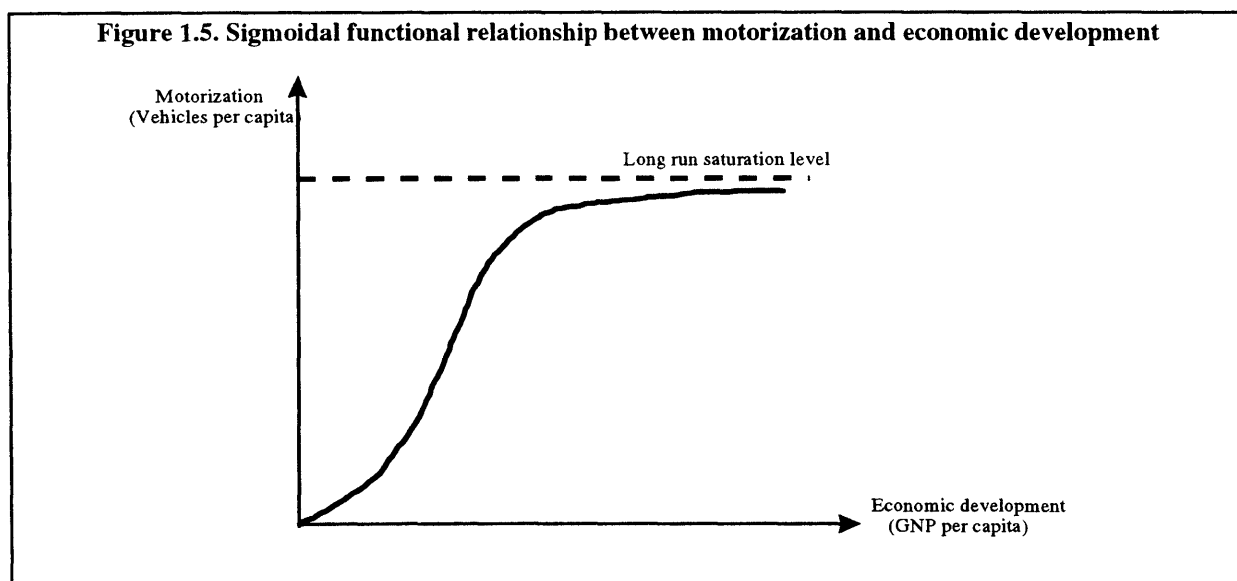
Figure 1.4. Economic development and motorization trends in Korea, 1969-1993



Sources: United Nations [1995]; World Bank [1995].

confirmed a positive relationship between economic development and motorization, the issue is far from resolved [Gakenheimer and Steffes 1995; Hau 1997; Newman et al. 1995; Nijkamp 1994; Stares and Liu 1995].

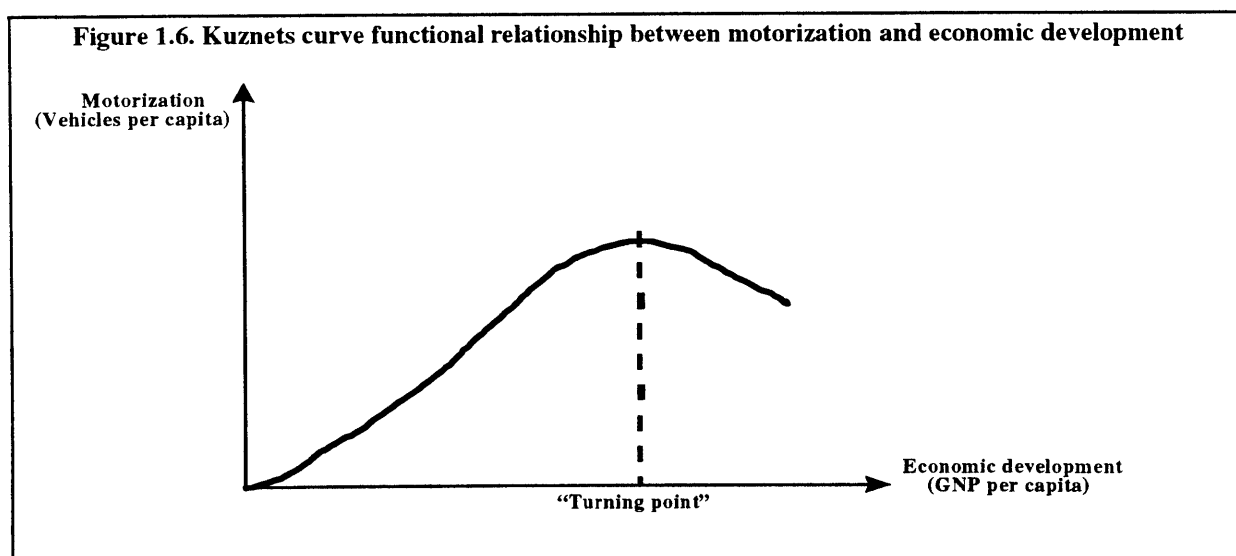
The assumptions underlying the *log-linear* or *sigmoidal* relational forms, as well as data limitations, raise questions about the validity of the findings to date. A survey of the existing literature indicates that the empirical estimates of income elasticity of motorization exhibit a wide variation--from a low of 0.3 for developed countries to a high of 1.95 for developing countries. Such variation in estimates is inconsistent with the specification of log-linear relational form, which imposes an *a priori* restriction of *constant* income elasticity of motorization. The sigmoidal relational form (see Figure 1.5) does allow for variation in income elasticity of motorization but restricts it to only *non-negative* values. In other words, it *a priori* rules out the possibility that higher income in the long run can *ever reduce* the dependence on motor-vehicles.



The fact is that a long-term positive relationship between economic development and motorization is neither inevitable nor automatic. For example, recent empirical research in environmental economics suggests a long-term inverse-U relationship between economic development

and environment. Such relationships, known as *environmental Kuznets curves*, have been confirmed for a variety of environmental indicators like levels of deforestation, sulfur dioxide emission and suspended particulate pollution [Grossman and Krueger 1994, Selden and Song 1992; Shafik 1994]. The rationale behind the environmental Kuznets curve is that economic development gives rise to a structural transformation in how an economy consumes and produces to conserve its scarce resources like environment more efficiently [Antle and Heidebrink 1995; Shafik 1994; Syrquin 1989]. Over time, such structural transformation may, in fact, reverse the expected positive relationship between economic development and environmental degradation. It should be noted that the original notion of the Kuznets curve can be traced to the seminal work by Simon Kuznets⁴ [1955] who demonstrated a long-term inverse-U relationship between economic development and income inequality. Now, any variable with a similar inverse-U relationship with economic development is said to exhibit a Kuznets curve.

Given that motorization entails adverse environmental impacts, can we expect motorization to exhibit a Kuznets curve, i.e., an inverse-U relationship with economic development (see Figure 1.6)?



Arguably, a Kuznets curve for motorization does not follow directly from the environmental Kuznets curves, which apply to environmental pollution itself rather than to pollution sources like motorization.

⁴ Simon Kuznets later received the Noble Prize in economics, partly for this research contribution.

However, it is *conceivable* that the structural transformation that produces Kuznets curves for pollution can produce the same for pollution sources as well.

The critical question is whether there indeed exists a Kuznets curve for motorization. If it does not exist, economic development will necessarily mean an ever-increasing dependence on motor-vehicles. On the other hand, if it does exist, economic development will lead to a long-term structural transformation in the economy that will reduce dependence on motor-vehicles (either directly through change in consumer preferences, or indirectly through social pressure on government to engage actively in policy interventions). The motivation of the proposed research lies in determining which of these development paths best describes the current motorization trends. As noted earlier, this information is essential for reliable estimates of long-term trends in motorization and its associated externality costs--both at global and national levels. They are thus critical ingredients to the development of sustainable motorization policies. The identification of the turning point per capita income level, if any, is also helpful in crafting motorization policies that are consistent and appropriate for different stages of economic development.

1.3 Research Objectives and Contributions

My research objective is to analyze--both theoretically and empirically--the long-term relationship between economic growth and automobile dependence. Specifically, the research seeks to:

- Analyze theoretically as to why the long-term relationship between economic development and motorization may exhibit Kuznets curve. Motorization is defined in terms of a country's dependence on motor-vehicle and is measured as per capita motor-vehicle ownership.
- Develop a large data base (annual data for 50 developing and developed countries over a period of 25 years, 1969-1993) for econometric analysis of the long-term relationship between economic development and motorization at the aggregate level.
- Test empirically as to whether the Kuznets curve provides a statistically better description for the long-term relationship between economic development and motorization than the sigmoidal and log-linear relationships commonly used in the existing literature.

- Estimate the income elasticity of motorization at different levels of economic development.
- Develop a simple microeconomic model to investigate the relationship between automobile dependence and income growth at the individual level, and to explore its policy implications.

The research makes several distinctive contributions to the existing literature. First, it is the only study to explore--both theoretically and empirically--the possible existence of a Kuznets curve for motorization. The conceptual and theoretical analyses clearly demonstrate the plausibility of the existence of an inverse U-relationship between economic development and motorization. Second, the empirical analysis not only provides strong support for the existence of a Kuznets curve for motorization, but also shows that the Kuznets curve does indeed provide a statistically better description of the long-term relationship between economic development and motorization (in terms of per capita ownership) than either the sigmoidal or the log-linear form commonly used in the existing literature. Finally, the cross-country, time series data base developed for the empirical analysis is much larger than any used in the existing studies on economic development and motorization.

The research is organized as follows: Chapter 2 provides a theoretical analysis of the long-term relationship between economic development and motorization. Chapter 3 uses national level aggregate data -- cross-sectional time-series pooled data across 50 countries over 25 years (1969-1993) -- for empirical analysis of the long-term relationship between economic development and motorization. Chapter 4 develops a simple microeconomic model of the relationship between income growth and automobile dependence at the individual level and investigates its policy implications. Finally, Chapter 5 summarizes the research and the policy implications of its major findings.

CHAPTER 2: Economic Development and Motorization: A Theoretical Analysis

2.1 Why Might Motorization Exhibit an Inverse-U Relationship with Economic Development?

An intuitive question is why motorization should be affected by economic development in anything but a positive fashion. The intuition usually goes: as per capita income rises with economic development, so should per capita demand of motor-vehicles and, hence, so should motorization. This argument misses the potential interaction between economic development and structural adjustments to mitigate the adverse impacts of motorization as a country develops economically. As research in environmental economics indicates, economic development may lead to a structural transformation in the economy that reduces environmental degradation (either directly through change in consumer preference, or indirectly through policy interventions) beyond a “turning” level of economic development [Cropper and Griffiths 1994]. To understand theoretically as to how such a transformation might work in the case of motorization, we use the microeconomic framework. From standard microeconomic consideration, the demand for per capita motor-vehicle ownership (i.e., motorization) will depend on the per capita income and *relative* price of motor-vehicle ownership. It should be pointed out that economic factors like income and price are not the exclusive determinants of motorization. Many non-economic factors like social status of women, household size, etc. are also determinants of motorization, and their effects could be substantial in the short-run. However, here we focus primarily on economic factors since we are interested in the long-term trends in motorization.

2.1. 1. Relationship between demand for per capita motor-vehicle ownership and per capita income:

The income elasticity of motor-vehicle ownership will determine whether an increase in per capita income under constant relative price of motor-vehicle ownership leads to an increase in demand for per capita motor-vehicle ownership. Making the realistic assumption that motor-vehicle ownership is at least a “normal good” (i.e., income elasticity is positive but less than 1) at very low levels of income, we can conclude that a rise in per capita income will increase the demand for per capita vehicle

ownership (see Figure 2.1). In fact, it is more likely that motor-vehicle ownership is a “superior good” (i.e., income elasticity is greater than 1) at very low levels of income; so the positive income effect on the demand for per capita vehicle ownership will be substantial. Based on how the income elasticity of motor-vehicle ownership changes over different levels of income, it follows that the demand path (the *Engel curve*) of per capita motor-vehicle ownership with respect to per capita income can take three forms (see Table 2.1 and Figure 2.2): (1) continually increasing; (2) S-shape; and (3) inverse-U shape.

From an intuitive behavioral perspective, the S-shaped form for the Engel curve is appealing based on the notion that per capita demand for motor-vehicles is likely to reach a “use saturation” limit, simply because of individual time constraint even if there is no income constraint. However, as Table 2.1 and Figure 2.2 show, what would be the actual form of the Engel curve is essentially an empirical issue that depends on the income elasticities of motorization. We *cannot* rule out the theoretical possibility that the income effect alone may produce an Engel curve that resembles the Kuznets curve in terms of inverse-U relationship between per capita income and per capita motor-vehicle ownership. In Chapter 4, we develop a simple microeconomic model to explore further this theoretical possibility.

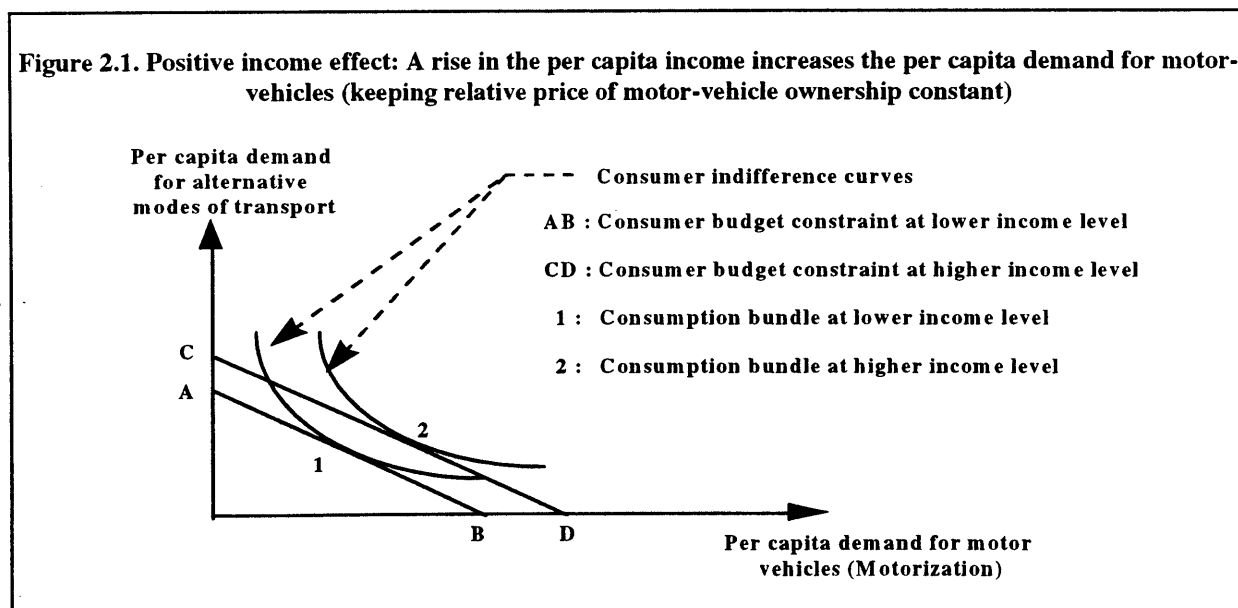
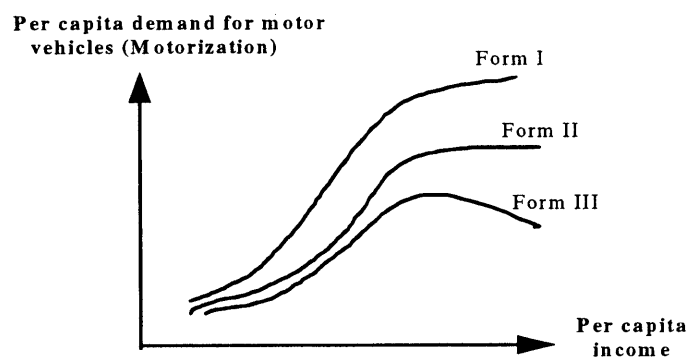


Table 2.1. Some potential forms of the demand path of per capita motor-vehicle ownership with respect to per capita income

Income elasticity, ε_I , of per capita motor-vehicle ownership for			Form of demand path of per capita motor-vehicle ownership w.r.t. per capita income (Engel curve)
Low income range	Medium income range	High income range	
$\varepsilon_I > 1$ (Superior good)	$0 < \varepsilon_I < 1$ (Normal good)	$0 < \varepsilon_I < 1$ (Normal good)	<i>Continually increasing</i> - initially at an increasing rate and then at a decreasing rate (Form I)
$\varepsilon_I > 1$ (Superior good)	$0 < \varepsilon_I < 1$ (Normal good)	$\varepsilon_I = 0$ (Neutral good)	<i>S-shape</i> : initially increasing at an increasing rate, then increasing at a decreasing rate, and finally remaining constant (Form II)
$\varepsilon_I > 1$ (Superior good)	$0 < \varepsilon_I < 1$ (Normal good)	$\varepsilon_I < 0$ (Inferior good)	<i>Inverse U-shape</i> : initially increasing at an increasing rate, then increasing at a decreasing rate, and finally decreasing at a decreasing rate (Form III)

Figure 2.2. Potential forms of demand path of per capita motor-vehicle ownership with respect to per capita income (keeping the relative price of motor-vehicle ownership constant)



2.1.2. Relationship between demand for per capita motor-vehicle ownership and relative price :

From the standard law of demand, the relative price⁵ elasticity of motor-vehicle ownership is always negative. Thus, any increase in the relative price of motor-vehicle ownership will reduce the per

⁵ The relative price of motor vehicle ownership represents the total cost to a motor vehicle user in terms of vehicle acquisition and usage relative to the total cost of alternative modes of transport.

capita demand for motor-vehicles (see Figure 2.3). In other words, the relationship between the per capita demand for motor-vehicle ownership and the relative price of motor-vehicle ownership will follow the standard downward sloping demand schedule, with income remaining constant (see Figure 2.4). The higher the price elasticities of motorization, the higher will be the drop in per capita demand for cars for a given increase in relative price.

Figure 2.3. Negative price effect: A rise in the relative price of motor-vehicle ownership reduces the per capita demand for motor-vehicles (keeping per capita income constant)

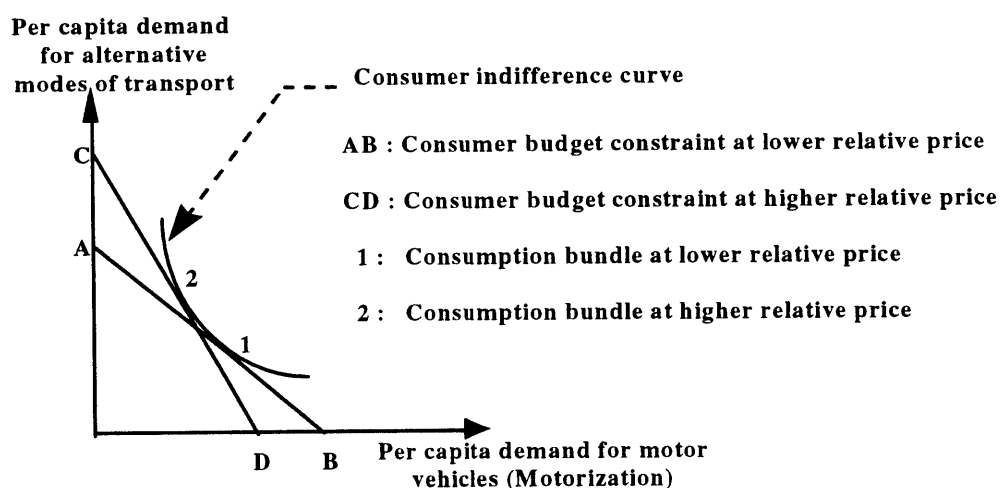
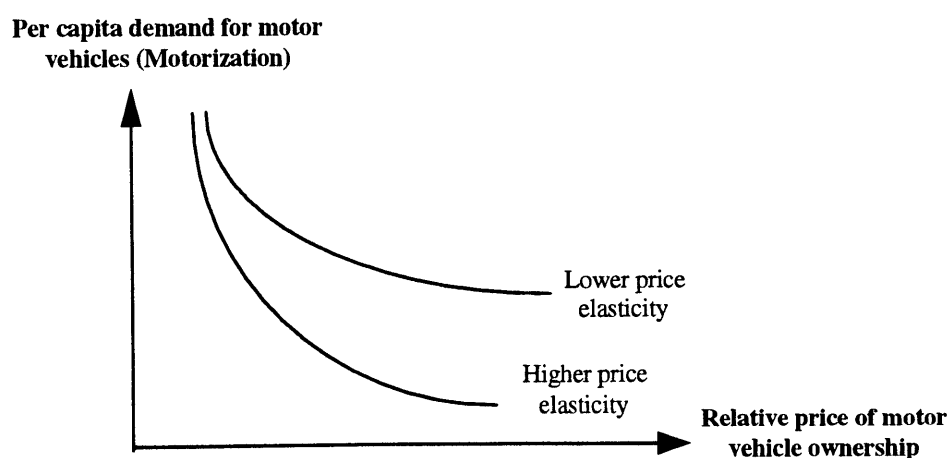
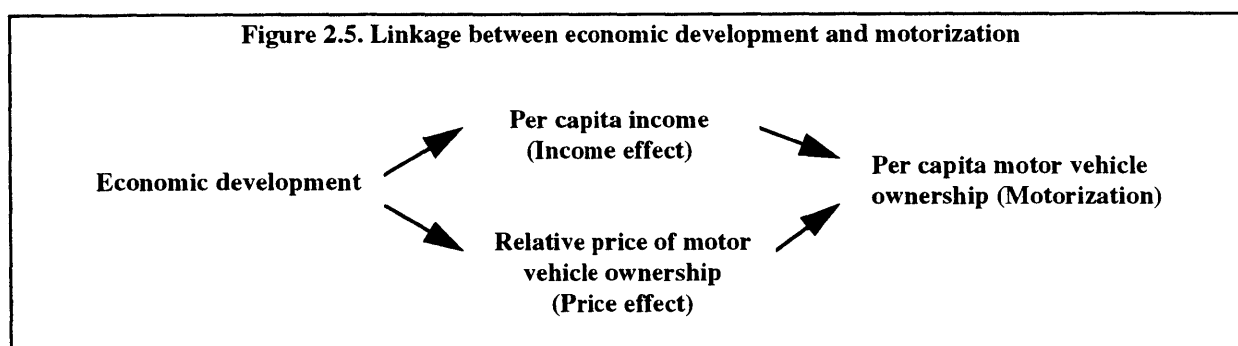


Figure 2.4. Demand schedule of per capita motor-vehicle ownership with respect to its relative price (keeping per capita income constant)



2.1.3. Relationship between economic development and motorization:

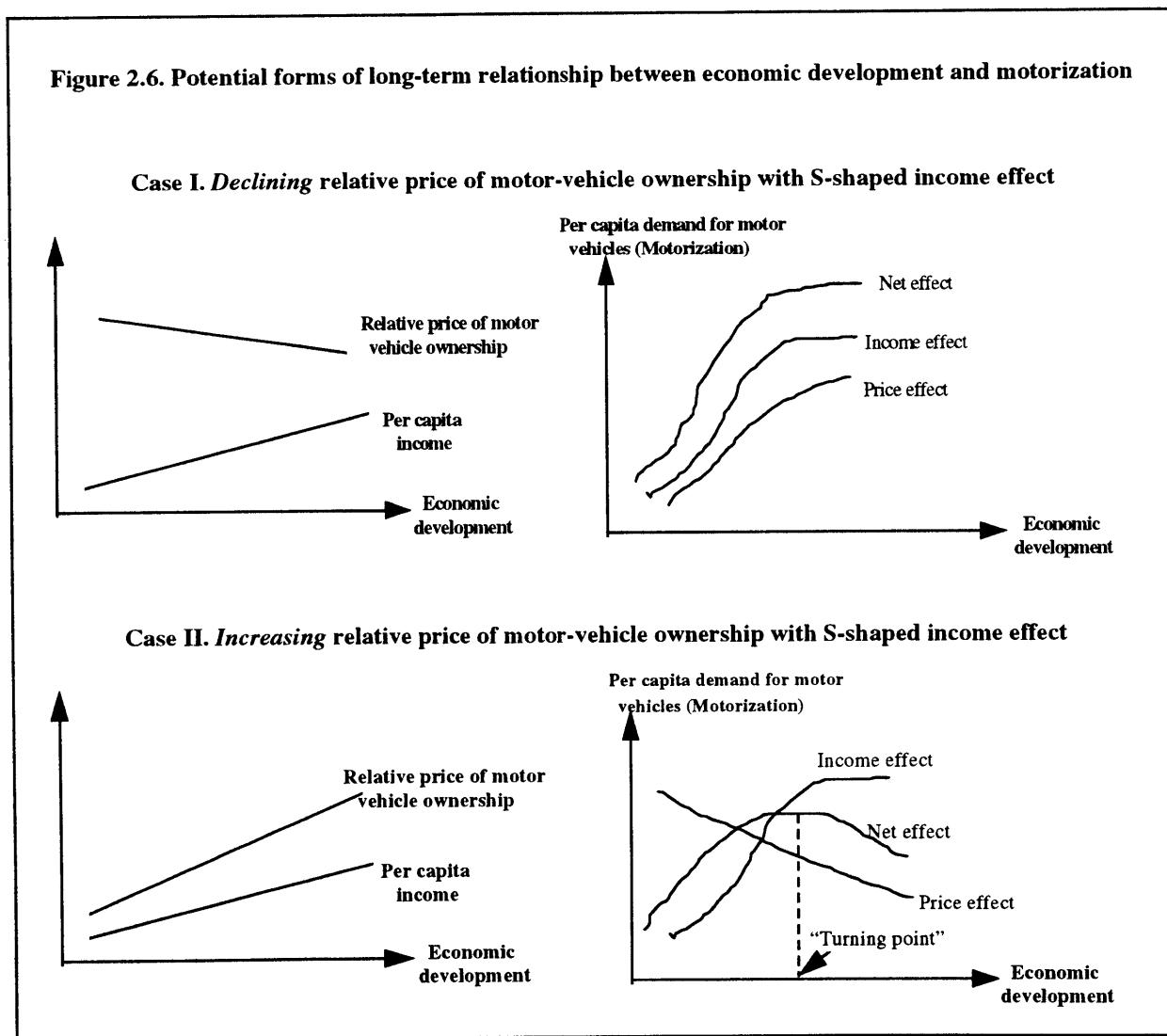
To understand the long-term relationship between economic development and motorization (per capita motor-vehicle ownership), one should first recognize that it involves the *simultaneous* effects of income and relative price changes on the demand for per capita, motor-vehicle ownership. As an economy develops, it affects motorization through its *intermediate* impacts on the per capita income and on the relative price of motor-vehicle ownership (see Figure 2.5).



The impact of economic development of a country on its per capita income is obvious and is positive by definition. However, its impact on the relative price of motor-vehicle ownership is less than obvious. One can argue either way. The relative price of motor-vehicle ownership might go down with economic development due to declining usage cost (induced by better quality infrastructure, that reduces vehicle operating cost) as well due to declining acquisition cost (induced by better production technology and competitive pressures on the supply side, that lower the price of vehicles). On the other hand, economic development may also lead to social pressure on government to engage actively in policy interventions to reduce the external costs of motorization. Such policy interventions can translate to an increased relative price for motor-vehicles to internalize the external costs of motorization. Depending on the case, the long-term relationship between economic development and motorization can take various forms (see Figure 2.6). What would be the actual form of the long-term relationship

between economic development and motorization is an empirical question and will depend critically on how the relative price of motor-vehicle ownership changes with economic development.

As Figure 2.6 (Case I) shows, if the relative price of motor-vehicle ownership is declining with economic development, a positive income effect is reinforced by a positive price effect to result in a continually increasing per capita demand for motor-vehicles. On the other hand, if the externality costs



of motorization are high enough, government policy interventions to internalize such cost may lead to an increasing relative price of motor-vehicle ownership. In that case, the policy-induced negative price effect may more than offset the positive income effect on per capita demand for motor-vehicles. The

result would be a decline in per capita demand for motor-vehicles after a certain “turning point” level of economic development, i.e., a long-term inverse U-relationship between economic development and motorization (Case II in Figure 2.6). In other words, even if motorization follows a sigmoidal or S-shaped relationship with income alone based on “use saturation” argument, it can still end up having an inverse-U relationship with economic development because of the price effect. Putting it all together, the above conceptual microeconomic framework clearly demonstrates that, contrary to popular notion, a long-term positive relationship between economic development and motorization is neither inevitable nor automatic.

2.2 Analytical Structure to the Conceptual Framework

We now give analytical structure to the earlier conceptual microeconomic framework for investigation of the long-term relationship between economic development and motorization. A motor-vehicle user’s decision problem can be structured as:

$$\begin{aligned} &\text{Maximize } \mathbf{M}(m, a) \\ &\quad m, a \\ &\quad \text{subject to the income constraint: } P_m m + P_a a = I \end{aligned} \tag{2.1}$$

where: $\mathbf{M}(\cdot)$ = Mobility function based on motor-vehicles and alternative modes of transport

m = Demand for per capita motor-vehicle ownership (motorization)

a = Demand for per capita alternative modes of transport

P_m = User price of motor-vehicle ownership

P_a = User price of alternative modes of transport

I = Per capita income spent on transport

The above decision problem is exactly analogous to the standard microeconomic utility maximization problem subject to income constraint. If we know the specification of the mobility function, we can solve for the user’s demand for motor-vehicle ownership and alternative modes of transport. In general,

it follows from the structure of the above decision problem that the demand for per capita motor-vehicle ownership (motorization) will be a function of the user price of motor-vehicle ownership, the user price of alternative modes of transport and the income spent on transport:

$$m = f(P_m, P_a, I) \quad (2.2)$$

To understand how motorization, m , will change with economic development, E , we can use the comparative static analysis of the functional expression (2.2):

$$dm/dE = (\delta m / \delta P_m) \cdot (dP_m/dE) + (\delta m / \delta P_a) \cdot (dP_a/dE) + (\delta m / \delta I) \cdot (dI/dE) \quad (2.3)$$

Equation (2.3) can be written in terms of corresponding elasticities as:

$$N^m_E = \eta^m_{P_m} N^{P_m}_E + \eta^m_{P_a} N^{P_a}_E + \eta^m_I N^I_E \quad (2.4)$$

where the various elasticities with their expected signs (shown within parenthesis) are:

$\eta^m_{P_m}$ = Own-price elasticity of motorization (-ve)

$N^{P_m}_E$ = Elasticity of price of motorization with respect to economic development (+ve or -ve)

$\eta^m_{P_a}$ = Cross-price elasticity of motorization with respect to alternative modes of transport (+ve)

$N^{P_a}_E$ = Elasticity of price of alternative modes of transport with respect to economic development
(+ve or -ve)

η^m_I = Income elasticity of motorization (+ve; may be zero or -ve at high income)

N^I_E = Elasticity of income with respect to economic development (+ve)

From equation (2.4) and the expected signs of various elasticities, it follows that the expected sign of *total* or *derived* elasticity, N^m_E , of motorization with respect to economic development can be both positive or negative. In other words, the long-term relationship between motorization and economic development can be either positive or negative. Two crucial factors that will determine whether motorization increases or decreases with economic development are the price elasticity, $N^{P_m}_E$, of motorization and the price elasticity, $N^{P_a}_E$, of alternative modes of transport with respect to economic development. For example, if the externality costs of motorization are high enough, government policy

interventions to internalize such cost may lead to an increasing *relative* price of motor-vehicle ownership. In that case, N^{Pm}_E and N^{Pa}_E will be positive and negative, respectively. The result, as evident from expression (2.4), could be a reversal of sign of the *total* elasticity, N^m_E , of motorization from positive to negative, thereby producing a long-term inverse U-relationship between economic development and motorization (Case II in Figure 2.6). The point is whether that would indeed be the case is an empirical question, but can not be ruled out theoretically. That is the premise and focus of this research. Before we get into the empirical analysis of the long-term relationship between motorization and economic development, it is therefore worthwhile to get some idea of the externality costs of motorization and the trends in policy interventions to reduce or internalize those costs.

2.3 Externality Costs of Motorization

The four primary externality costs of motorization are due to:

1. Automotive environmental pollution,
2. Road traffic accidents,
3. Road traffic congestion, and
4. Urban sprawl

Although air and noise pollution are considered to be most important, the scope of automotive environmental pollution also includes land and water pollution. The vehicle emissions responsible for air pollution include carbon dioxide, carbon monoxide, oxides of nitrogen, sulfur dioxide, volatile organic compounds, lead particulate and smoke. Factors responsible for land pollution include waste oils, tires, batteries, spoil tips, and rubble from road works as well as acid rain caused by automotive emissions. Water pollution is caused by road surface run-offs, waste oils, etc. Table 2.2 shows the various damages of the primary externality costs of motorization.

Even as the debate on the accuracy of the existing estimates continues, all indications are that the externality costs of motorization may be substantial. For example, a study by the World Resources Institute [MacKenzie et al. 1992] puts the externality costs to the society--that is, those not borne

Table 2.2 . Various damages of the primary externality costs of motorization

Externality Costs	Damages
1. Automotive air pollution	<ol style="list-style-type: none"> 1. Death, illness, and physical pain and suffering of victims 2. Psychological pain and suffering of victims, their relatives and friends 3. Need for hospital and medical services 4. Aesthetic (visual) degradation 5. Damage to buildings and infrastructure from dirt and corrosion 6. Adverse impacts of acid rain on drinking water, agriculture, forests, commercial and recreational fisheries and natural flora and fauna 7. Ozone layer depletion 8. Contribution to the enhanced greenhouse effect
2. Road traffic noise	<ol style="list-style-type: none"> 1. Temporary and permanent hearing loss 2. Interference with sleep 3. Interference with social and business communications, and reduction of enjoyment of leisure activities 4. Tension, irritability, fatigue, headaches and contributions to cardiovascular and digestive disorders
3. Road traffic accidents	<ol style="list-style-type: none"> 1. Death, injury, physical pain and suffering of victims 2. Psychological pain and suffering of victims, their relatives and friends 3. Damage to property 4. Increased traffic congestion 5. Need for police, emergency, legal, hospital and medical services 6. Need for accident prevention measures
4. Road congestion	<ol style="list-style-type: none"> 1. Increased travel time 2. Lost economic production and higher production costs due to human and freight delays, higher labor turnover, higher delivery costs, difficulties in implementing "just-in-time" production systems 3. Increased operating costs and sub-optimal use of vehicles 4. Psychological and physiological symptoms of stress, including heart disease and high blood pressure 5. Increased vehicle emissions due to low speed, idling 6. Possible increased accident risks
5. Urban sprawl	<ol style="list-style-type: none"> 1. Increased cost of public service provision 2. Increased automotive pollution due to longer commuting distance 3. Encroachment and damage of ecosystem from low density land use

Source: Compiled from BTCE/EPA [1994].

directly by the motorists--at about \$300 billion a year for the United States economy, or 5.3% of its GDP. That roughly translates to an indirect annual subsidy of \$2000 to each car owner to pay for road construction and maintenance, loss of economic activity from congestion, the cost of illness caused by air pollution, and medical care for the victims of nearly two million accidents a year in the United States. Another study by the Organization of Economic Cooperation and Development (OECD) [1990a] estimates that the typical externality costs of land transport in most developed countries are *at least* 2.5% of GDP, with motor-vehicles responsible for 90% of it. This lower figure excludes the costs of congestion and the wider aspects of environmental pollution such as noise and acid rain.

Unfortunately, most of the existing research on externality costs of motorization has focused on developed countries (see Table 2.3)--primarily because of the relative ease in data availability. The results for developing countries are far fewer and less rigorous, but seem to be worse than developed countries. For example, the cost of road traffic congestion in the United States is about 1.3% of its GNP in contrast to nearly 10% of Thailand's GNP for Bangkok city alone [OECD 1994; Sayeg 1992]. In Kenya, economic losses from road accidents *alone* amount to 1.3% of its GDP [World Bank 1996].

Table 2.3. Indicative externality costs of motorization for selected developed countries
(per cent of gross domestic product)

Country	Type of social costs				Total
	Noise	Pollution	Air Pollution	Accidents	
France	0.24		0.15	0.78	0.90 - 3.00
Germany	0.20		0.20 - 0.34	0.75	2.00
Netherlands	0.23		0.14 - 0.23	0.51	2.00
UK	0.50		0.05 - 0.12	0.51	3.20
USA	0.06 - 0.21		0.10 - 0.21	0.60 - 0.72	1.00 - 1.55
Australia	0.11		0.21	0.60	1.06
Overall average*	0.15 - 0.24		0.12 - 0.21	0.63 - 0.70	1.38 - 1.94

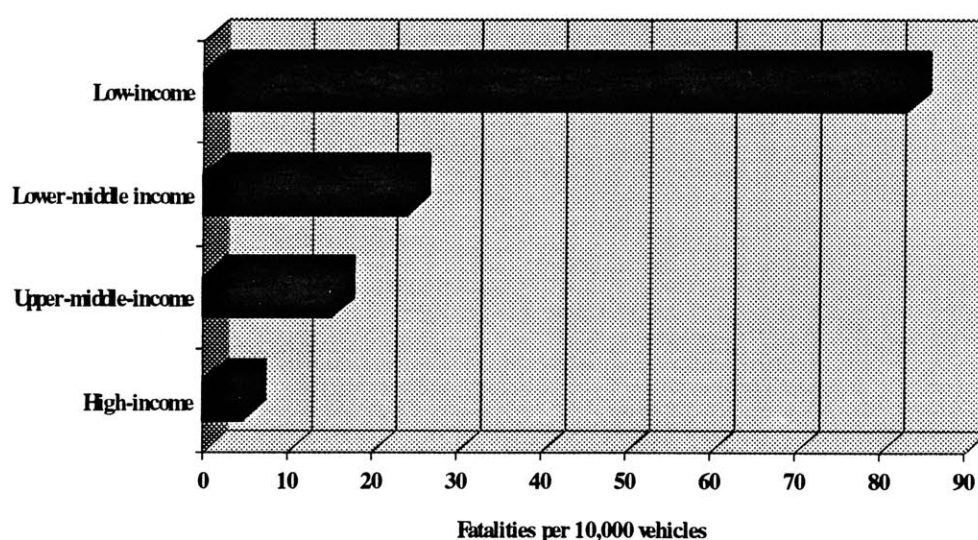
* Average of countries in this table, weighted by GDP.

Source: BTCE/EPA [1994]

The trend in road fatality rates across countries at different stages of economic development is also quite revealing (see Figure 2.7). The developing world accounted for a majority of the estimated 885,000

deaths from traffic accidents in 1993. In India, for example, roadway death rates (road deaths per 1,000 vehicles) are 18 times higher than those in Japan, accounting for 60,000 fatalities per year [WRI 1996]. China--with only 6.5 million motor-vehicles--experience approximately 50,000 deaths a year in road accidents. This level of mortality from road accidents is higher than that (approximately 40,000 deaths a year) in the United States with nearly 200 million motor-vehicles [IRF 1994, Roberts 1995]! Empirical evidence also clearly shows that the amount of air pollution emitted per motor-vehicle in developing countries is much higher than that in developed countries [Faiz et al. 1990]. The reasons are not hard to understand--developing countries do not have the technological or financial capacity to combat auto pollution at the same level as developed countries.

Figure 2.7. Road fatality rates, by country income group*, 1993



Source: World Bank [1996]

* Refer to the Appendix for definitions of income groups.

As only a few urban cities usually account for the lion's share of the national motor-vehicle fleet in a developing country, they bear most of the burnt of the negative externalities of motorization. The externality costs of motorization in cities like Bangkok, Mexico City, and Cairo are widely recognized as causing significant dents in respective national GDPs [Sathaye et al. 1994]. For example, the cost of

traffic congestion in Bangkok alone is estimated at nearly 10% of Thailand's GNP [Sayeg 1992]. The air quality in Bangkok has deteriorated so severely that at least one million of the city's residents were treated in 1990 for smog-related health problems such as emphysema and asthma. In Mexico City, the total cost of air pollution--most of which is caused by automobiles--is estimated at about 0.4% of Mexico's GDP [Margulis 1992]. Lead concentrations in some areas of Cairo are five to six times higher than the global norms set by the World Health Organization, and as a result the lead content in the blood of children in Cairo is about five times as high as that of children in rural Egypt [Stickland 1993]. Also, a recent study concluded that there was a high probability that the mental capacity of the children in Cairo was diminished due to exposure to high ambient lead concentrations [Sathaye et al. 1994].

2.4 Trends in Policy Interventions to Tackle Externality Costs of Motorization

As the externality costs of motorization has become more and more apparent, recent years have seen a marked shift in public attitude towards motorization [Hart and Spivak 1993; Newman and Kenworthy 1996; Roberts 1995; WRI 1996]. Motor-vehicles are increasingly seen as the worst polluters of urban air and the biggest producers of carbon dioxide, the chief suspect in global warming. As one would expect, public pressure for policy interventions to internalize the externality costs of motorization has become particularly strong in developed countries. Britain and other Western European countries have experienced a recent surge in public resistance to road-building. In Japan, two recent court cases, in Osaka and Kobe, have gone in favor of protesters who wanted urban motorway plans changed to cut noise and pollution. A new ring road planned for Tokyo is bogged down in opposition from residents, a new phenomenon in Japan [Carson 1996].

In developed countries with high population density, there is a growing recognition that simply building more roads will not reduce traffic congestion or accidents, but will only worsen automotive air pollution. Instead, attention has increasingly turned to policy interventions that manage and limit demand [Stares and Liu 1995; Strickland and Wayne 1995]. The main policy strategy has been to

increase the cost of private motor-vehicle ownership relative to the cost of using public transport, thereby producing a policy induced negative price effect on private motor-vehicle ownership [Nijkamp 1994; World Bank 1996]. Such strategies include policy interventions like higher fuel tax and parking fee, increased time and space restrictions, road pricing as well as better management and expansion of public transport system to make it a more attractive alternative to private transport.

The British government has already committed to increasing fuel prices by at least 5% in real terms, and has been doing so for the last four years [*Economist* 1996c]. The movement of cars, especially private cars, has come under increasing restriction. Singapore is already well known for its effective “area licensing scheme” that puts severe time and space restrictions on movements of private cars. In France, the government has just introduced a clean-air law giving local prefects power to close city centers to cars when air pollution rises above levels that pose a threat to health. In Italy, the center of Milan is closed to petrol-powered cars. Most Dutch cities have adopted “traffic calming” measures that include banning all vehicles in central downtown areas to convert them into pedestrian malls [Carson 1996; Munn and Patterson 1995]. In fact, worried that governments might ban conventional cars from city centers because of pollution and congestion, European car manufacturers are already taking preemptive action by working on developing more fuel efficient and smaller cars [*Economist* 1996b]. There has also been evidence of an emerging European “congestion consciousness” that shows a more positive public attitude towards adoption of road pricing [Grieco and Jones 1994]. In many Western European countries like Denmark, France, Germany, Netherlands, and Switzerland, integration of fares and services across transit modes (e.g., bus to rail) has made public transportation use easy and competitive with the automobile in terms of travel time and comfort [OECD 1995].

As policy interventions to reduce automobile dependence have increased, their effectiveness have also come under scrutiny [Button 1994]. Of particular interest, especially in the context of this research, is to what extent such policy interventions have been successful in reducing motorization in the face of rising income. In other words, to what extent have the policy-induced negative price effects

been able to offset the positive income effect from economic development? Some preliminary empirical evidence at the city level between the United States (which has used relatively few policy interventions) and Western Europe suggest that such policy interventions may have been able to break or at least weaken the expected positive relationship between motorization and income. As shown in Table 2.4, per capita car use grew three times more in Los Angeles (LA) than in Zurich, while public transit declined in LA and grew substantially in Zurich. Similar patterns are evident in other United States and

Table 2.4 . A comparison of income, car use and public transit use in Zurich and Los Angeles

City	GNP per capita (\$US, 1991)	Growth in annual car use per capita, 1980-1990 (Km)	Growth in public transit use per capita, 1980-1990
Los Angeles, USA	21, 560	2,584	- 4 trips
Zurich, Switzerland	33,510	879	+ 137 trips

Source: Newman et al. [1995]

European cities, including large cities such as Amsterdam, Paris, Frankfurt, London and Stockholm [Munn and Patterson 1995, Newman et al. 1995]. Naturally, a question arises as to whether such casual empirical evidence of policy-induced weakening of the positive link between automobile dependence and income in a few wealthy countries can hold up to the test of systematic econometric analysis of large-scale data. In other words, are these empirical observations indicative of a generalizable systematic trend? That is the question that we try to answer in our next chapter.

CHAPTER 3: Economic Development and Motorization: An Empirical Analysis

3.1 The Data

The data base developed consists of annual data for 50 selected countries for 25 years (1969-1993) and is much larger than any data base used in the existing studies on motorization. The countries (see Appendix) selected represent a wide range of developing and developed economies from all over the world. The data base contains national level data on five variables: (1) total number of registered motor-vehicles (excludes motorcycles); (2) GNP per capita in current US dollar; (3) population; (4) population density; and (5) urbanization. In addition, it contains Consumer Price Index (CPI) data for the United States from 1969 to 1993. The data base is created from various secondary data sources like the *World Tables* [World Bank 1981, 1995], *United Nations Statistical Yearbook* [UN 1976, 1982, 1984, 1995], *World Motor-vehicles Data* [AAMA 1992] and *World Road Statistics* [IRF 1994].

Urbanization is measured in terms of the proportion of total population living in urban areas [World Bank 1981, 1995]. We use per capita motor-vehicle *ownership* (specifically, motor-vehicles per 1,000 population) as the measure of motorization or automobile dependence for an economy. Per capita vehicle *usage* (specifically, average miles traveled per year per vehicle per capita) would arguably be a better measure of automobile dependence. However, such data are very hard to get, especially for developing countries. Since our empirical analysis requires a large number of developing countries for investigating the relationship of motorization at lower levels of economic development, we selected per capita vehicle ownership as the measure of motorization. The selection also has the advantage of comparability of our results directly with those in the existing literature, which have mostly used per capita motor-vehicle ownership to estimate the income elasticity of motorization [Gakenheimer and Steffes 1995; Stares and Liu 1995]. Table 3.1 below presents the summary statistics of the major variables in the data base.

Table 3.1 Sample average* of the major variables in the data base

Country income level in terms of GNP per capita (1993 US\$)**	Motorization (vehicles per 1,000 population)	GNP per capita (1993 US\$)	Urbanization (% of urban population)	Population density per square kilometer
Low (Less than \$725)	11	318	25	82
Lower middle (\$725 - \$2,895)	36	1,124	46	55
Upper middle (\$2,896 - \$8,955)	89	2,318	65	52
High (More than \$8,995)	337	9,746	74	121

* Sample average are calculated across all the 50 countries over the entire 25 year (1969-1993) period.

** Country income levels are defined as per the World Bank classification [1994]. Also see the Appendix for the specific countries in each income level.

Figures 3.1 - 3.3 use the 1993 observations for all the fifty countries in the data base to draw the scatter plots of motorization versus economic development, urbanization and population density, respectively. It should be noted that a scatter plot between motorization and any variable is helpful only in providing a general sense of the relationship of motorization with that variable, since it does not control for the effect of other variables that might influence motorization. For example, the scatter plot between motorization and population density in Figure 3.3 looks ambiguous on first sight. However, if one takes into account that the cluster of data points on the bottom left corner are essentially countries with very low income, then it seems likely that motorization and population density has a negative relationship when controlled for the level of economic development. One way to determine whether that is indeed the case is to use multivariate regression analysis technique to estimate empirically the relationship between motorization and population density by simultaneously controlling for the effect of other pertinent variables that might influence motorization. In fact, that is the approach used in this research to study the long-term relationship between motorization and economic development. The specific empirical models are presented in the next section, and the results of multivariate regression estimates of the models are presented in Section 3.2.

Figure 3.1 Scatter plot of motorization versus economic development, 1993
(Based on 50 data points comprising the 1993 observations for each of the 50 countries in the data base)

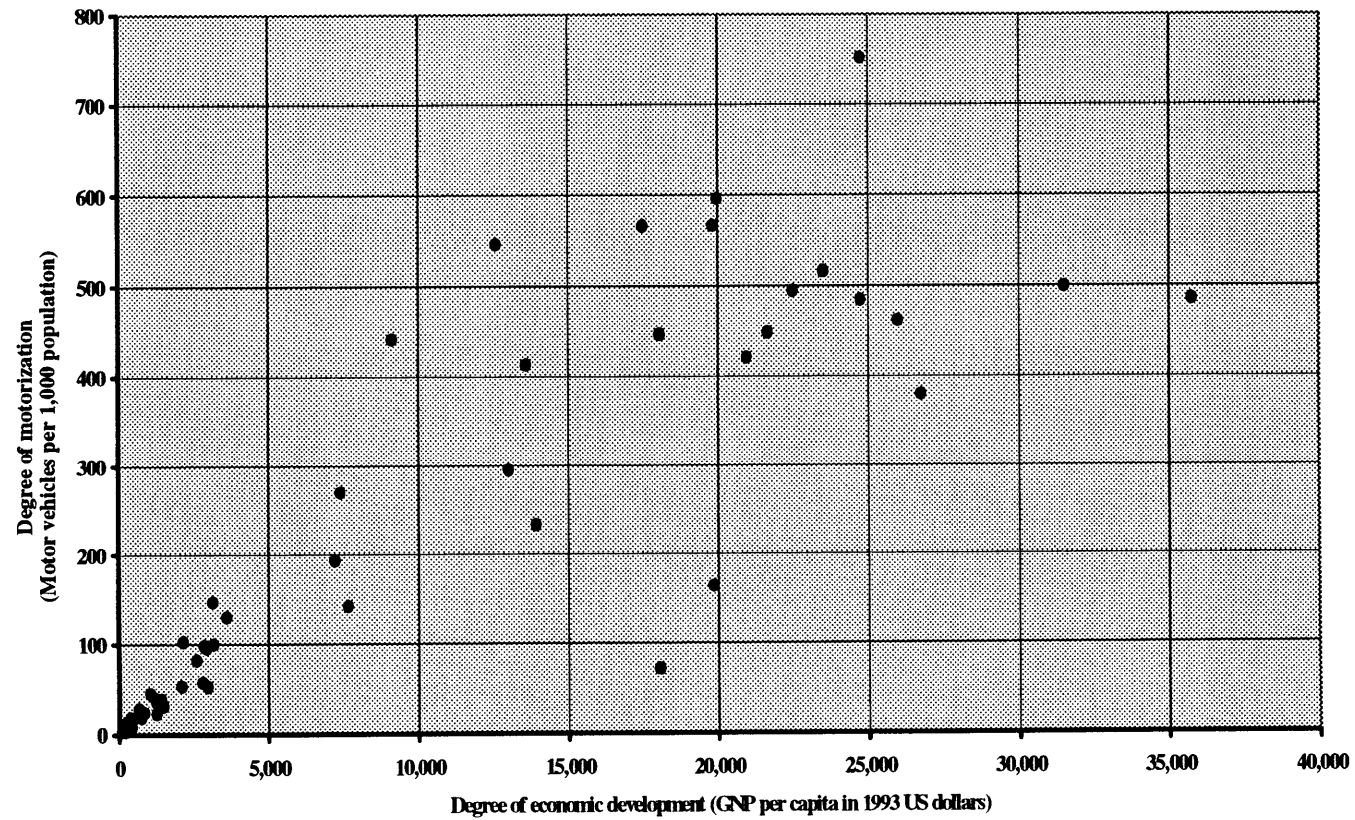


Figure 3.2 Scatter plot of motorization versus urbanization, 1993
(Based on 50 data points comprising the 1993 observations for each of the 50 countries in the data base)

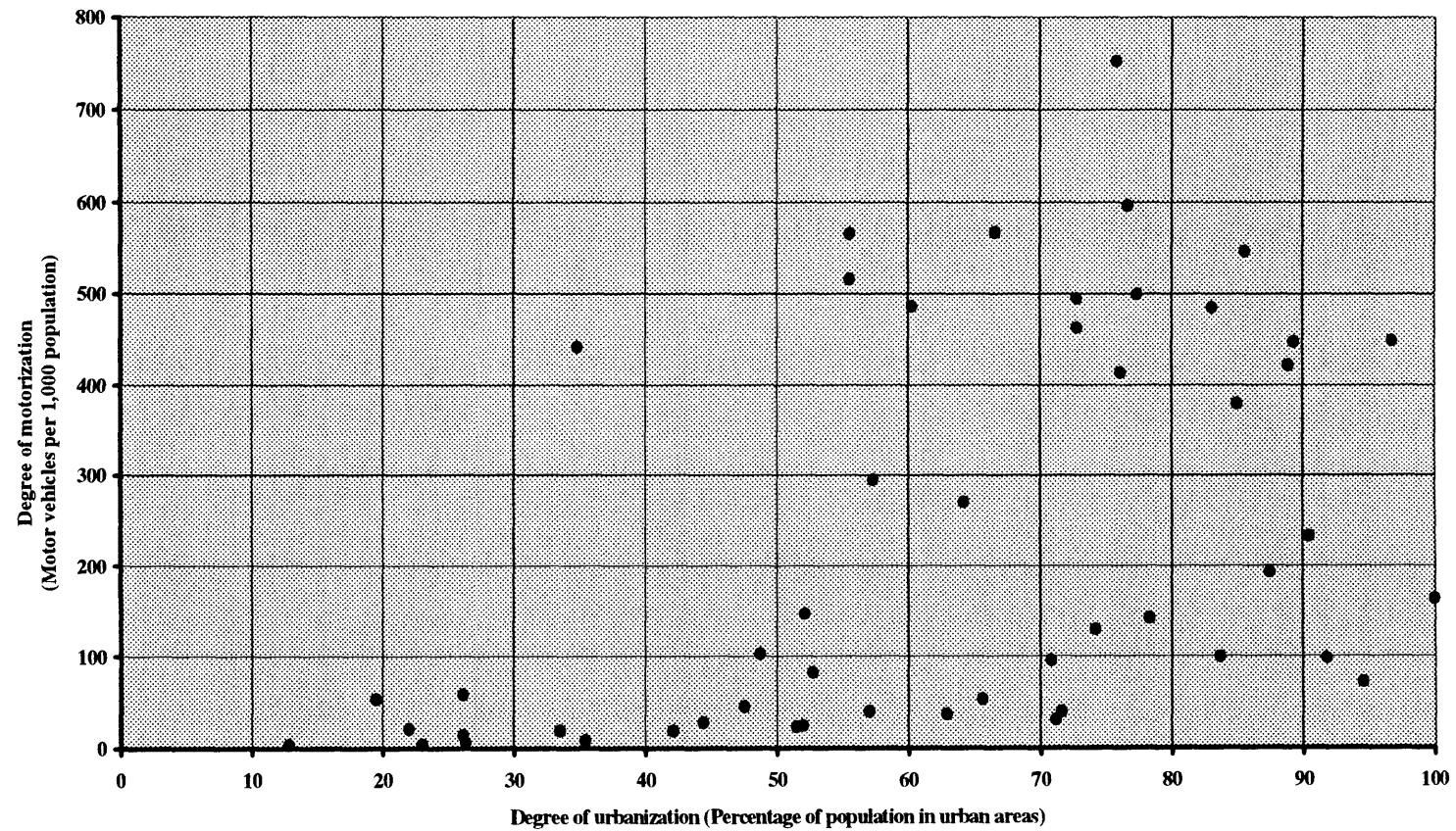
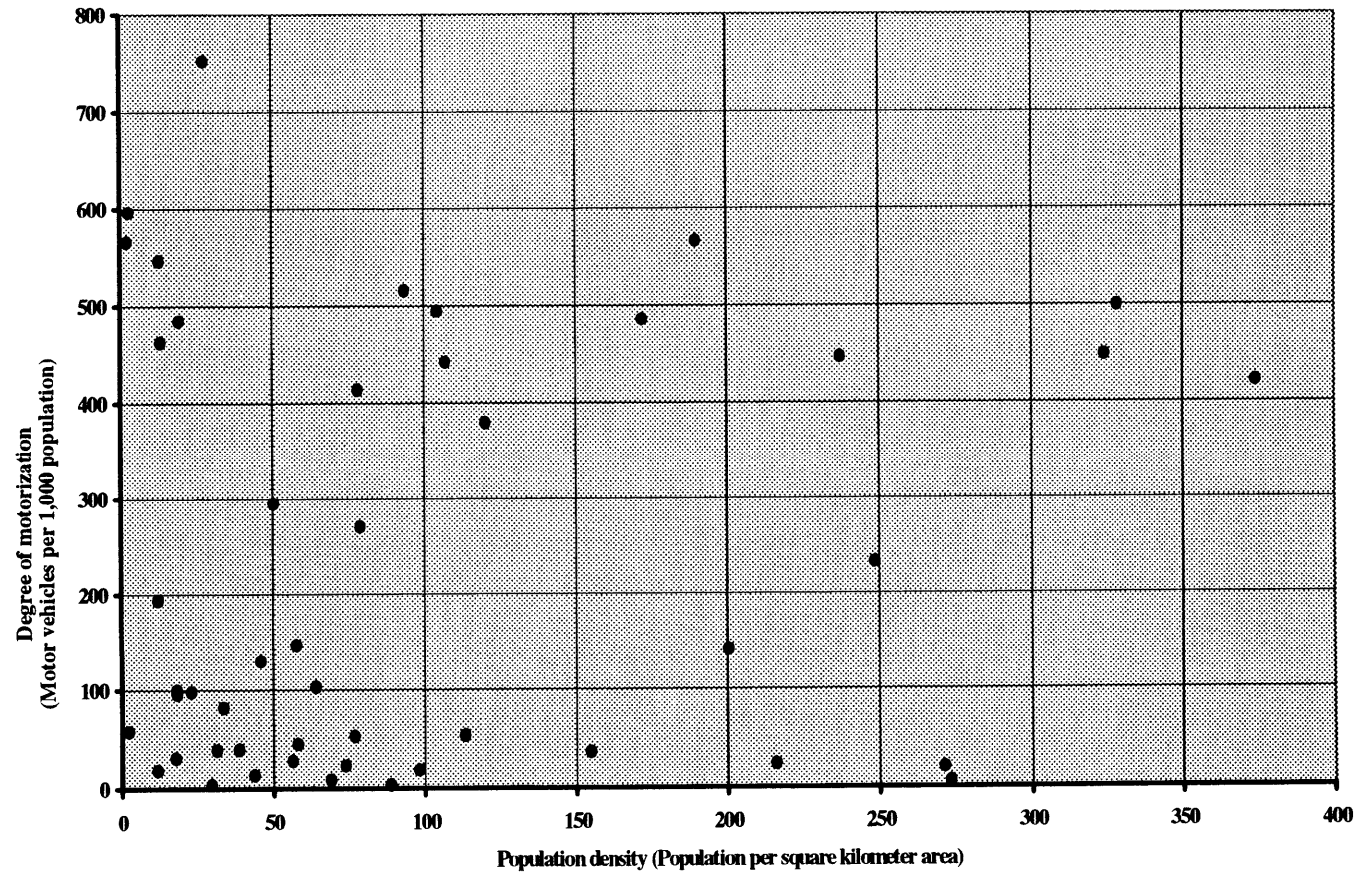


Figure 3.3 Scatter plot of motorization versus population density, 1993
(Based on 50 data points comprising the 1993 observations for each of the 50 countries in the data base)



3.2 Empirical Models

To study the long-term relationship between motorization and economic development, we adopt the standard “reduced-form” modeling instead of the “structural-form” modeling approach⁶ used in the existing literature. We use three different empirical models in terms of specification of the functional form: (1) log-linear; (2) quasi-logistic (sigmoidal); and (3) quadratic (Kuznets). The motivation is to test whether there exists a Kuznets curve for motorization and, if so, whether the Kuznets curve provides a statistically better description for the long-term relationship between economic development and motorization than the log-linear and sigmoidal functional forms used in the existing literature. The full specification of the three empirical models is given below⁷:

$$1. \text{ Log-linear model: } \log(M_{it}) = \beta_{0,i} + \beta_1 \log(GNPPC_{it}) + \sum_{j=1}^n \gamma_j \log(X_{itj}) + \varepsilon_{it} \quad (3.1)$$

$$2. \text{ Sigmoidal model: } \log\{M_{it} / (S - M_{it})\} = \beta_{0,i} + \beta_1 \log(GNPPC_{it}) + \sum_{j=1}^n \gamma_j \log(X_{itj}) + \varepsilon_{it} \quad (3.2)$$

$$3. \text{ Kuznets model: } M_{it} = \beta_{0,i} + \beta_1 (GNPPC_{it}) + \beta_2 (GNPPC_{it})^2 + \sum_{j=1}^n \gamma_j X_{itj} + \varepsilon_{it} \quad (3.3)$$

where the variable, M_{it} , is the indicator of the level of motorization in country i at time t . As discussed earlier, we have used per capita vehicle ownership (specifically, number of motor-vehicles per 1,000 population) as the measure of motorization. The variable, S , is the saturation level of motorization used in the sigmoidal model. Following the common practice in the existing literature, we use the value of 450 vehicles per 1,000 population as the saturation level based on current evidence from developed countries [Button et al. 1993]. Although the saturation level is based on the

⁶ The reduced-form modeling approach has several advantages in terms of data requirements and estimation, and is widely used to determine long-term relationship between economic development and environment [Antle and Heidebrink 1995; Grossman and Krueger 1994; Selden and Song 1992; Shafik 1994].

⁷ See Button et al. (1993) for the derivation of the specification of sigmoidal model.

notion of natural time constraints on per capita car use (thus on per capita car ownership), it is expected to be influenced by income level as well as policy interventions. This brings out an important conceptual distinction between the sigmoidal model and our proposed Kuznets model. In the sigmoidal model, once the saturation or peak level of motorization is reached, it continues to stay at that level independent of any further increase in income level with economic development. This concept is certainly consistent with the “user saturation” argument; however it ignores the interaction between policy interventions and rising income, and the impact there of on users’ demand for motor-vehicles. On the other hand, the Kuznets model allows the conceptual possibility that the peak level of motorization may decline with further increase in income level with economic development because of concomitant policy interventions.

The independent variable, $GNPPC_{it}$, is the GNP per capita in country i at time t in 1993 constant US dollars and measures the level of economic development in a country. The independent variable, X_{ij} , is the j^{th} covariate of motorization in country i at time t . In our estimation, we have used two covariates: (i) *urbanization*, which is measured by the percentage of the total population in a country living in urban areas, and (ii) *population density*, which is measured by the number of people per square kilometer of area in a country. We have not included any policy-intervention variables as independent variables because they are expected to be systematically correlated with GNP per capita (as more interventions are expected at higher levels of economic development) and are thus captured implicitly through GNP per capita in our reduced-form models [Cropper and Griffiths 1994; Grossman and Krueger 1994]. Our model specifications allow the constant term, $\beta_{o,i}$, to differ across countries to control for country specific unique factors (e.g., topography, climate, culture, etc.) that might affect the level of motorization⁸. The model coefficients to be estimated are β and γ , while ε is the random error term.

⁸ This is a common formulation in reduced-form modeling of environmental Kuznets curve and is known as a “fixed effects” model [Cropper and Griffiths 1994].

The quadratic functional form of the Kuznets model with respect to GNP per capita reflects the hypothesized inverse-U relationship between motorization and economic growth. The hypothesis will be supported if the coefficients β_1 and β_2 are statistically significant and the estimated signs are positive for β_1 and negative for β_2 . Urbanization is expected to have a positive impact on the level of motorization in a country by inducing greater demand for motor-vehicles through increased need for mobility in an urban setting, *ceteris paribus* [Button et al. 1993; OECD 1995]. So we expect the coefficient for urbanization to be positive. On the other hand, high population density puts a large constraint on the supply of physical road infrastructure and is thus expected to have a negative impact on the level of motorization, *ceteris paribus* [Hau 1997]. Thus, the expected sign for the coefficient of population density is negative.

A few observations are in order regarding the problem of “missing variables” in any reduced form modeling approach [Grossman and Krueger 1994]. It is expected that other social and geographic factors (e.g., household size, proportion of female in labor force, typical climate conditions, etc.) are also determinants of motorization, and their effects could be substantial in the short run. However, partly because relevant data (especially for developing countries) are scarce and partly because some of these factors are difficult to quantify, their quantitative relationships with motorization is hard to estimate reliably [Stares and Liu 1995]. Also, from a methodological point of view, it is not a critical issue for several reasons. First, GNP per capita is the predominant determinant of long-run vehicle ownership and many of the social factors like household size, proportion of female in labor force are likely to be systematically correlated with GNP per capita. Second, by making the constant term in our model country specific, we alleviate the problem further by picking up some of the effect of the above variables on motorization. Finally, the objective of this research is not to develop a short-run *predictive* model of motorization, but to estimate the long-run relationship between economic development and motorization.

3.3 Estimation Results

We use the pooled cross-section and time-series country data from our compiled data base to estimate the three empirical models.⁹ Table 3.2 shows the ordinary least squares (OLS) regression estimation results for the three models.¹⁰ The results (statistically significant coefficients β_1 and β_2

Table 3.2 . Regression results for the reduced form empirical models

Independent variable	Estimates of coefficient values		
	Log-linear model	Sigmoidal model	Kuznets model
GNP per capita	0.42* (11.1)	1.06* (19.1)	0.05* (12.6)
GNP per capita squared	n.a.	n.a.	- 0.12 E-5* (- 5.7)
Population density	1.64* (8.62)	2.24* (12.3)	- 0.06* (- 6.6)
Urbanization	- 0.54* (- 6.74)	- 0.15 (- 0.70)	3.09* (16.13)
Number of observations *	1250	1250	1250
Adjusted R ²	0.91	0.93	0.97
Turning point (1993 \$US)	21,900	n.a.	n.a.

- Notes: 1. Dependent variable is motorization measured in vehicles per 1,000 population.
 2. For Log-linear and Sigmoidal models, the dependent and the independent variables are in their logarithmic forms.
 3. “*” signifies coefficient is statistically significant at 0.01 level. Numbers below the coefficients in parenthesis are *t*-statistics.
 4. n.a. = Not applicable.
 5. ♣ Number of observations consist of 25 annual observations for each of the 50 countries in the sample.

⁹ Methodologically, cross-sectional, time-series pooled data is better for estimating the long-term effect than pure time-series data [Stares and Liu 1995].

¹⁰ Models are estimated using the Prais-Winsten technique to correct for autocorrelation [Cropper and Griffiths 1994]. Unlike the Cochrane-Orcutt technique, this technique has the advantage of using all the observations, and it produces estimates that have the same asymptotic properties as the BLU (“best linear unbiased”) estimators [Kmenta 1986]

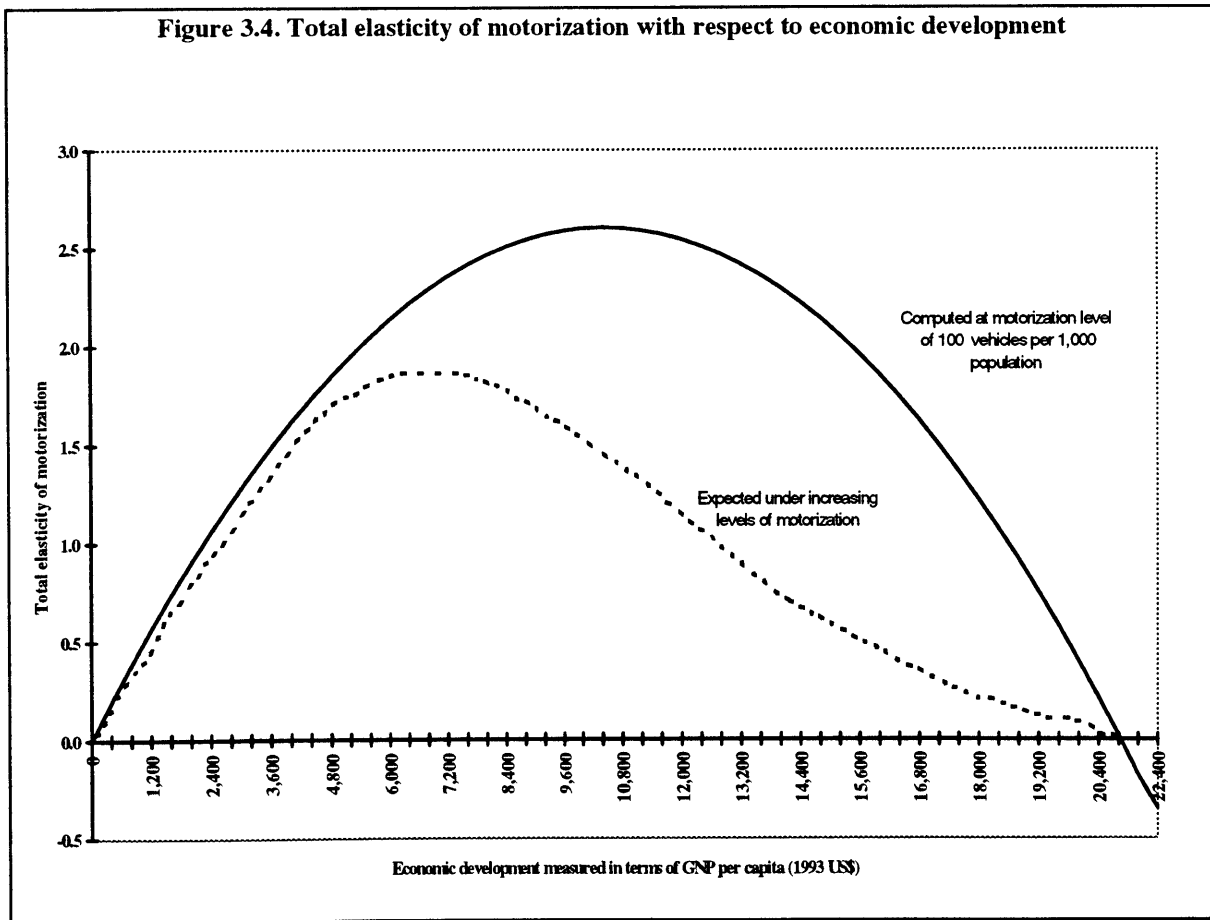
with positive and negative signs respectively) provide strong support for the existence of a Kuznets curve for motorization. Further, the results indicate that the Kuznets model provides a statistically better description for the long-term relationship between motorization and economic development than the log-linear and sigmoidal functional forms commonly used in the extant literature. First, it provides a better model fit in terms of adjusted R^2 values than the other two models. Second, in contrast to the Kuznets model, which has all statistically significant coefficient estimates with expected signs, both log-linear and sigmoidal models suffer from coefficient estimates with wrong signs for the population density and urbanization variables.

The findings suggest that increased policy interventions in recent years, especially in developed countries, may have raised the relative price of motor-vehicle ownership sufficiently high to break the usual positive link between economic development and motorization. The estimated value of the turning point per capita income level (whose value is given by $-\beta_1/2\beta_2$) of motorization is \$21,900 in 1993 US dollars. Some examples of countries that have already crossed this turning point are Austria, Belgium, Denmark, France, Germany, Holland, Japan, Singapore, Switzerland and the United States. It should be emphasized that the empirical evidence of the existence of a Kuznets curve for motorization does *not* necessarily mean an actual reduction of motor-vehicles in a country. It simply implies that once the country reaches the turning point level of economic development, its stock of motor-vehicle is predicted to grow at a *slower* rate relative to its growth of population. Further, for any given level of economic development, the actual level of motorization will be higher or lower than the predicted level based on the degree of urbanization and population density. Our relatively high estimate of the turning point income level at \$21,900 stems from the fact that the true externality costs of motorization have come to be recognized only recently. So even though many of the developed countries already have the institutional capability, it is only in recent years that public attitude has changed enough to allow hitherto politically unacceptable, but effective, policy interventions to control motorization.

Based on the Kuznets model in equation (3.3), the *total* or *derived* elasticity, $N^m_{E, it}$ of motorization with respect to economic development (measured in terms of GNP per capita) for country i at time t can be expressed as:

$$N^m_{E, it} = (\beta_1 + 2 \beta_2 \text{GNPPC}_{it}) (\text{GNPPC}_{it}/M_{it}) \quad (3.4)$$

The existence of a Kuznets curve for motorization implies that the total elasticity of motorization also has a turning point up to which it increases with income and then decreases, and ultimately turns negative (see Figure 3.4). The estimated value of the turning point per capita income level (which is given by $-\beta_1/4\beta_2$) of the total elasticity of motorization is \$10,950 (1993 US\$). Using a motorization



level of 100 vehicles per 1,000 population for illustration, the findings indicate that motorization starts off as a “normal good” (income elasticity greater than zero but less than 1) until the income reaches about \$2,600 and then begins to enjoy the status of a “luxury good” (income elasticity greater than 1) over a wide income range of \$2,600 to \$20,500. However, it reverts back to a “normal good” after the income has climbed to \$20,500 and turns into an “inferior good” (income elasticity less than zero) as the income continues to climb beyond \$21,900.

It should be noted that the above illustrative elasticity calculations are made at a constant motorization level of 100 vehicles per 1,000 population. In reality the level of motorization will increase with income until the turning point. As evident from the elasticity expression in equation (3.4), since the elasticity of motorization decreases with an increase in the level of motorization for any given level of GNP per capita, the evolution of income elasticity of motorization will be skewed towards a lower level of income (as shown by the dashed line in Figure 3.4). This conclusion from the Kuznets model is borne out from consistent empirical evidence of much larger income elasticity of motorization in developing countries relative to that in developed countries--sometimes by almost a factor of 6 [Hau 1997; Stares and Liu 1995]. Although such a conclusion also follows from sigmoidal model based on “use saturation” explanation, the Kuznets model is distinctive in that it allows for negative total elasticity of motorization beyond the turning level of economic development.

CHAPTER 4: Income Growth and Automobile Dependence: A Microeconomic Model

4.1 Model Formulation

In our earlier theoretical analysis of the long-term relationship between economic development and motorization, public policy interventions on the relative price of motor-vehicle ownership were thought to play an important role in shaping the relationship. The focus in this chapter is to develop a simple microeconomic model to investigate the relationship between income growth and automobile dependence at individual level *without* any active public policy intervention. Essentially, we theoretically explore the nature of the demand path (the Engel curve) of motorization with income (refer to Section 2.1 in Chapter 2).

We consider an individual rational decision maker who has to choose her residential location with respect to her job. She has a monotonic preference for the environmental quality of the residential location and for the use of own transport for commuting. Being rational, her choice is based on the maximization of her utility--subject to her monetary budget constraint--in terms of the extent of environmental quality offered and usage of own transportation possible under various residential location options. This optimization problem of the decision maker can be characterized in the following analytical form:¹¹

$$\begin{aligned} & \text{Maximize } U[E(d), m] \\ & (d, m) \end{aligned} \tag{4.1}$$

subject to the monetary budget constraint:

$$t_o p_o + t_p p_p + wd/s = wfT \tag{4.2}$$

where:

¹¹ To focus on the decision maker's trade-off between her demand for environmental quality and own transportation, the demand for "all other non-transportation goods" is assumed fixed in the model. Analytically, this is reflected in the constant fraction, f , of T used to pay for her actual and opportunity costs of commuting. Although the assumption seems restrictive, relaxing it does not change the qualitative implications of the model.

$U(.)$: the utility function of the decision maker such that $\delta U/\delta E(d) > 0$ and $\delta U/\delta m > 0$.

$E(d)$: the environmental quality of a residential location at distance d from the job location.

m : the proportion of job commuting done through own transportation.

d : the distance between the residential and job locations.

w : job wage rate.

T : total working time available.

f : fraction of T used to pay for commuting cost.

s : average speed of commuting traffic (same for both own and public transportation).

$t_o = md/s$: commuting time in own transportation.

$t_p = (1 - m)d/s$: commuting time in public transportation.

p_o : cost of own transportation per unit commuting time.

p_p : cost of public transportation per unit commuting time.

4.2 Model Implications

To get an explicit analytical solution into the decision maker's above optimization problem, we need to specify the utility function. A standard linear, compensatory utility function of the following form is specified¹²:

$$U[E(d), m] = \alpha_1 d + \alpha_2 m \quad (4.3)$$

where α_1 and α_2 are the decision maker's preference weights for environmental quality and own transportation respectively. The functional form assumes that the environmental quality of residential location has a positive relation with its distance from the job location.

Using a standard Lagrangian technique for solving constrained optimization problem, relations (4.1), (4.2) and (4.3) can be solved for the decision maker's optimal choice for residential location, d^* , and usage of own transportation, m^* , as given below:

$$d^* = [\alpha_2 f Tsw / \alpha_1 (p_o - p_p)]^{1/2} \quad (4.4)$$

$$m^* = [\alpha_1 f Tsw / \alpha_2 (p_o - p_p)]^{1/2} - w / (p_o - p_p) - p_p / (p_o - p_p) \quad (4.5)$$

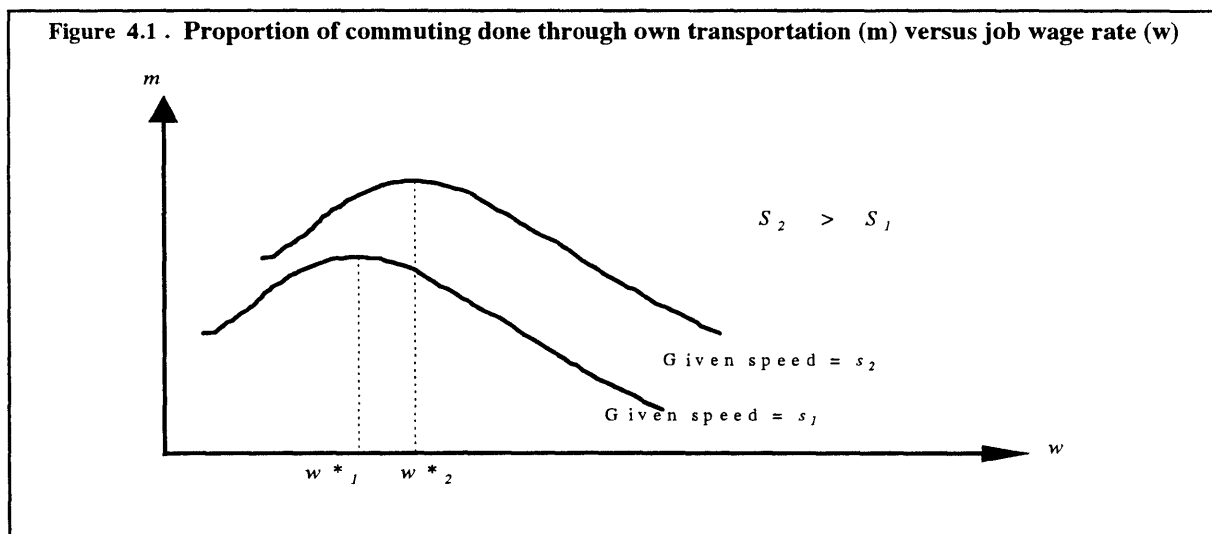
¹² The linear, compensatory utility functions are widely used in industrial organization and consumer research literature [Chintagunta et al. 1991; Tirole 1988].

Comparative static analyses of d^* and m^* with respect to various variables provide several interesting implications. A few of the more interesting implications are discussed below:

- Positive sign for $\delta d^*/\delta w$ implies that as their income level rises, people's residential locations become more dispersed, *ceteris paribus*.
- Positive sign for $\delta d^*/\delta s$ and negative sign for $\delta d^*/\delta p_o$ imply that as average traffic speed increases or cost of own transportation decreases, people's residential locations become more dispersed, *ceteris paribus*. This has the interesting policy implication that an increased supply of road infrastructure (which reduces traffic congestion and increases average speed) and various policies (like lower fuel surcharge, lower import or excise duty on cars, free parking areas, etc.) that reduces cost of own transportation are likely to spur urban sprawls. Emergence of many of the sprawling cities in the United States and Australia seem to provide empirical support to this phenomenon. Also, the historical transformation of "walking cities" into "automobile cities" with the development of faster means of transport is consistent with this implication [Newman and Kenworthy 1996].
- Mixed signs for $\delta m^*/\delta w$ imply that as the income rises, the dependence on own transport increases at first and then declines, *ceteris paribus*. In other words, there is an inverse-U relationship (the Engel curve) between income growth and automobile dependence at the individual level, with the turning point income level, w^* , being given by: $w^* = [\alpha_1 f Ts(p_o - p_p)/4 \alpha_2]$. The intuition behind such an inverse relationship lies in spending an increasing proportion of the rising income in enjoying better environment even if it means switching to public transport.¹³ Although this implication follows from a simple micro-economic model, it suggests the

¹³ Such individual increased spending on "consumption" of better environment is likely to be influenced by a collective change in social values with economic development about what constitutes "good life". Recent

possibility of the existence of a Kuznets curve for motorization at the aggregate level. As the expressions for m^* and w^* indicate, the lower the average commuting speed, the lower is the motorization level as well as the “turning point” income level, *ceteris paribus* (see Figure 4.1). This has the interesting policy implication that, given comparable per capita income, “managed” motorization may, in fact, achieve a higher level of vehicle ownership (through greater efficiency in traffic flow) than “free market” motorization. Preliminary empirical evidence from Bangkok and Curitiba also seem to back up the implication--the average traffic speed in Curitiba is higher than that of Bangkok even though it has more motor-vehicles per thousand residents and comparable per capita income.



- Mixed signs for $\delta m^*/\delta p_o$ imply that as the cost of own transportation rises, the dependence on own transport increases at first and then declines, *ceteris paribus*. Again, it suggests an “inverse-U” relationship between cost of own transportation and automobile dependence at the individual level. When the cost of own transportation is relatively low, the additional benefit from increased dependence on own transportation continues to outweigh the additional cost until the cost of own

studies indicate that while total United States spending rose 15% over the past seven years, spending on new cars, cars, vans and trucks declined 28%, measured in constant dollars [WSJ 1997].

transport reaches a “turnover point” and induces a switch from own to public transport. This insight from the model is consistent with the recent trends in the share of public transport in several highly developed countries like Denmark and Switzerland which have used considerable policy interventions to internalize the social cost of motorization [Button 1994; Newman and Kenworthy 1996]. The interesting policy issue to note here is that such an internalization of social cost can be achieved either through direct public regulation policies (such as higher parking fee) that raises the actual cost of own transportation, or through indirect public information policies (such as public education campaign) that raise the perceived cost of own transportation. The thrust on public information policies and their successes in countries like Norway, Denmark, and Holland suggest that such policies can be more effective in the long run as they are likely to enjoy broader political support [Button 1994].

CHAPTER 5: Summary

The long-term relationship between economic development and motorization has been an active area of research in transportation economics. Existing research posits either a continuous positive relationship between motorization and income (log-linear models) or a saturation level of motorization at high incomes (sigmoidal or quasi-logistic models). Although empirical studies usually tend to confirm a positive relationship between economic development and motorization, the issue is far from resolved. The assumptions underlying the *log-linear* or *sigmoidal* relational forms, as well as data limitations, raise questions about the validity of the findings to date. A survey of the existing literature indicates that the empirical estimates of income elasticity of motorization exhibits a wide variation--from a low of 0.3 for developed countries to a high of 1.95 for developing countries. Such variation in estimates is inconsistent with the specification of log-linear relational form, which imposes an *a priori* restriction of *constant* income elasticity of motorization. The sigmoidal relational form does allow for variation in income elasticity of motorization but restricts it to only *non-negative* values. In other words, it *a priori* excludes the possibility that higher income in the long run can *ever* reduce motorization.

Interestingly, recent empirical research in environmental economics suggests a long-term inverse-U relationship between various environmental quality indicators (like level of deforestation or ambient concentrations of sulfur dioxide) and economic development. This so-called environmental Kuznets curve shows environmental quality worsening up until some “turning point” per capita income level and improving thereafter. Given that motorization inflicts considerable environmental and other externality costs on the economy, can we expect a Kuznets curve for motorization as well? Does continued economic development necessarily mean an ever-increasing dependence on motor-vehicles? Or will the increase in income lead to a long-term structural transformation in the economy that reduces (either directly through change in consumer preferences, or indirectly through social pressure on government to engage actively in policy interventions) dependence on motor-vehicles?

The motivation of this research lies in answering these questions and thus providing a better insight into the long-term dynamics of motorization process.

Specifically, the goal of this research had been to investigate--both theoretically and empirically--the long-term relationship between economic development and motorization, and to find if there is a Kuznets curve for motorization. The findings will allow a better forecast of the level of motorization in the long run as well as a more reliable estimate of the associated externality costs--both at global and national levels. They are thus critical ingredients to the development of sustainable motorization policies. The identification of the turning point per capita income level, if any, is also helpful in crafting motorization policies that are consistent and appropriate for different stages of economic development. It should be pointed out that non-economic factors like social status of women, household size, etc. are also determinants of motorization, and their effects could be substantial in the short-run. However, here we focus primarily on economic factors since we are interested in the long-term trends in motorization.

The research makes several distinctive contributions to the existing literature. First, it is the only study to explore--both theoretically and empirically--the possible existence of a Kuznets curve for motorization. Second, the theoretical analysis clearly demonstrates the plausibility of the existence of an inverse U-relationship between economic development and motorization. Further, the empirical analysis not only provides strong support for the existence of a Kuznets curve for motorization, but also shows that the Kuznets curve does indeed provide a statistically better description of the long-term relationship between economic development and motorization (in terms of per capita ownership) than either the sigmoidal or the log-linear form commonly used in the existing literature. Finally, the cross-country, time-series data base developed for the empirical analysis is much larger than any used in the existing studies on economic development and motorization.

It is important to underscore the policy implications of our findings. First, even though our empirical analysis shows the existence of an inverse-U relationship between motorization and

economic development, there is no reason to believe that the relationship is an automatic one. In principle, the motorization level might decrease automatically when people with rising income levels become more concerned with adverse environmental impacts of motorization and reduce their demand for own transportation. Although our empirical methodology does not allow us directly to test that hypothesis, the insights from our microeconomic model seem to be consistent with that hypothesis. However, as our theoretical analysis as well as the review of current efforts to control motorization suggest, the strongest link between income and motorization is, in fact, through an induced policy response. The results indicate that high economic development may bring about policy interventions that may indeed reduce motorization beyond a certain turning point in per capita income. Such a turnaround is likely to be induced by the rising externality costs of motorization and consequent intensified policy interventions by governments to internalize such costs through a higher relative price of motor-vehicle ownership. As nations or regions experience greater prosperity, their citizens demand that more attention be paid to the non-economic aspects of their living conditions, and they are willing to accept more stringent policy measures to discourage motorization. Their governments also possess greater institutional capability (e.g., technological and financial capacities) to internalize the externality costs of motorization.

Second, it should be emphasized that there is nothing at all inevitable about the relationship pattern between motorization and economic development that has been observed. The pattern detected is only a reflection of existing policies under the prevailing socio-economic, technological, and political conditions. We suspect though that our relatively high estimate of the turning point at \$21,900 is more of a reflection of the fact that the true externality costs of motorization have come to be recognized only recently. Even though many of the developed countries already have the institutional capability, it is only in recent years that public attitude has changed enough to allow hitherto politically unacceptable, but effective, policy interventions. As the high turning point is a reflection of historical policy interventions, it suggests that developing countries might not have the

luxury to follow the current motorization-development path by replicating the developed countries in terms of policy interventions.

As the magnitude of the true externality costs of motorization becomes increasingly apparent, developing countries need to make more active policy interventions at *comparable* stages of economic development than was done by developed countries to avoid following the current motorization-development path. As some of the externality costs (viz., carbon dioxide emissions on global warming) of motorization have global consequences, it is also to the interest of developed countries to provide the necessary technological and financial help to spur such an effort in developing countries. Over time, the turning point level of economic development is thus likely to decline.

Appendix

Countries in the Data Base

(Grouped according to the World Bank classification* based on GNP per capita in 1993 US dollars)

Low Income Countries (Less than \$725)	Lower Middle Income Countries (\$725 - \$2,895)	Upper Middle Income Countries (\$2,896 - \$8,955)	High Income Countries (More than \$8,995)
Egypt Ghana India Kenya Malawi Sri Lanka Tanzania Zambia	Botswana Colombia Costa Rica Dominican Republic Ecuador Indonesia Morocco Panama Peru Philippines Syria Thailand Turkey Venezuela	Argentina Brazil Chile Greece Malaysia Mexico South Korea	Australia Austria Belgium Canada Denmark France Hong Kong Ireland Italy Israel Japan Netherlands New Zealand Portugal Singapore Spain Sweden Switzerland United Kingdom United States

* See World Bank [1994].

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